Dynamical Control of Rapid Tropical Cyclone Intensification by Environmental Shears

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LONG-TERM GOALS

The long-term goal is to advance our understanding of mechanisms of the formation and explosive intensification of tropical cyclones (TCs). Of particular interests are the roles of the environmental horizontal and vertical shears and TC internal dynamical processes in changing the inner core structure and TC intensity.

OBJECTIVES

Improve our understanding of the mechanisms by which (a) 3-D environmental shears, in particular the low-level meridional shear and upper-level vertical shear affect inner core structure and intensity, and (b) the mesoscale vortices, outer spiral rainbands, inner spiral rainbands, and the eyewall interact and affect TC development and intensity change.

General science questions to be addressed are: (a) How is the asymmetric structure generated in association with the environmental forcing? (b) How does the change of the structure affect TC intensity?

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APPROACH

Our approach is to combine observational analysis, numerical modeling, and diagnostic analysis of the physical mechanisms.

1. Analyze observed data to identify environmental controls and internal structure changes in the (a) rapid development of tropical depressions into a tropical storm (TS formation), and (b) explosive intensification of tropical storms;

2. Design and perform controlled numerical experiments with a realistic hurricane model (TCM3) to reveal major processes determining by which the environmental forcing affects the structure and intensity.

3. Develop diagnostic tools for studying energetics, potential vorticity, angular momentum, and heat and moisture budgets. The budget diagnostics will help elucidate internal dynamic processes in the core region that could alter the thermodynamic efficiency of the TC intensification.

WORK COMPLETED

The role of downdrafts in the near core environment and in the rainbands in limiting the tropical cyclone intensity has also been studied using TCM3 (Wang 2002). The effect of dissipative heating associated with the turbulent kinetic energy dissipation rate, the Betts-Miller convective adjustment scheme and the Tiedke massflux convective parameterization scheme have been implemented into TCM3.

Observational analyses of tropical cyclone genesis using modern satellite products such as TMI and QuikSCAT. The analyses focus on two types of processes: the westward propagation of easterly waves associated with scale contraction and energy accumulation and Rossby wave energy dispersion and its interaction with the mean summer flow. Observational analyses of the rapid intensification, including the changes in inner core structure and large scale background flows.

A numerical study of the influence of TC-ocean interaction on the baroclinic TC motion has been completed, results are in written up stage. (Wu and Wang, to be submitted)

RESULTS

A. Sensitivity of TC intensity to cloud microphysical processes

It has been known that cloud microphysics can have a significant impact on the simulations of precipitation, however, there have been few studies so far that investigate the effect of cloud microphysics on tropical cyclones. In our study, three different cloud microphysics parameterization schemes are tested, including the warm-rain only cloud microphysics scheme, two mixed-ice phase cloud microphysics schemes in which one with the three-ice species of cloud ice-snow-graupel while the other with hail instead of graupel. It is shown that although the cloud structures of the simulated tropical cyclone can be quite different with different cloud microphysics schemes, intensification rate and final intensity are not very sensitive to the details of the cloud microphysics parameterizations.

This occurs because all the schemes produce similar level of rainbands, stratiform clouds and downdrafts.

B. TC genesis studies

Our preliminary analysis indicates that many TC genesis cases in the western North Pacific are associated with the easterly waves, TC energy dispersion, or combination of both. For the easterly wave cases, there is clear westward propagation of precipitation and wave energy signals prior to the cyclone genesis. They propagate from the central and eastern tropical Pacific. For the TC Rossby wave energy dispersion, we identify several cases in recent two years (year 2000-2001). In these cases, the wave train was clearly seen at the wake of a mature TC. However, not all mature tropical cyclones are accompanied by the wave train. It is found that the most important factor that determines the wave train is the TC intensity. Why is a new cyclone generated in the positive vorticity region of the Rossby wave train in some cases but not in other cases? We addressed this question by examining the characteristics of the large-scale flow field and convective instability. Our preliminary analyses indicate that the surface moisture distribution and associated convective available potential energy (CAPE) are important. We are currently analyzing the role of vertical shear and large-scale flow patterns.

In addition to observational analyses, we are currently carrying out the modeling study using a high-resolution TC model with an explicit convective heating scheme. In order to understand the role of the basic state, an anomaly model was developed in which the basic state is fixed with time. Our preliminary results indicate that the basic-state flow pattern plays a critical role in helping/prohibiting the tropical cyclogenesis in the western North Pacific.

C. Effects of air-sea interaction on TC motion (Wu and Wang, to be submitted)

How does the air-sea coupling affect the TC motion? Comparison of the track differences between the coupled and uncoupled numerical experiments indicates that the difference is sometimes significant while other times rather moderate, especially for fast-moving tropical cyclones. Why? The response of ocean surface temperature to the surface wind stress is remarkably asymmetric, thus the convective heating is also asymmetric due to oceanic feedback. The asymmetric convective heating affects the TC motion by two processes: generation of asymmetric flows, which may alter advection of symmetric PV, and modification of the PVT tendency, which may deflect the TC toward the maximum PVT area**.** It seems that the track difference depends on how these two processes compete with each other.

IMPACT/APPLICATIONS

This is the first extensive evaluation of the sensitivity of tropical cyclone intensification and intensity to the details of cloud microphysics parameterizations in a tropical cyclone model so far (Wang 2002). In comparison with the substantial sensitivity of simulated tropical cyclones to different cumulus parameterization schemes found in previous studies, the insensivity of the simulated tropical cyclone intensity from this study indicates the potential advantage in using explicit cloud microphysics in tropical cyclone models to improve the intensity forecasting. However, the warm rain-only cloud parameterization should be avoided because it usually produces too much rainfall.

TRANSITIONS

TCM3 has been installed for Prof. C.-C. Wu at the National Taiwan University to support their tropical cyclone research. Prof. Lance Leslie at the University of Oklahoma has recently requested our state-of-the-art cloud microphysics package. This package has also been successfully implemented into our IPRC regional climate model and works quite well. The original cloud microphysics scheme has been updated at BMRC and is continuously being tested in their operational forecast system. Our coupled model has been used by Florida State University (Prof. Zou) to investigate the air-sea coupling process and its impacts on TC intensification.

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Wang, B., and J. C. L. Chan, 2002: How the ENSO regulates tropical storm activity over the western North Pacific. *J. Climate*, (in press)

Wu, L., and B. Wang: How air-sea coupling affect the tropical cyclone beta drift. To be submitted.

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Wang, B., and J. C. L. Chan, 2002: How the ENSO regulates tropical storm activity over the western North Pacific. *J. Climate*, (in press)

Wang, B. and LinHo, 2002: Rainy seasons of the Asian-Pacific monsoon. *J. Climate*. 15, 386-398.

Wang, Y.: An Explicit Simulation of Tropical Cyclones with a Triply Nested Movable Mesh Primitive Equation Model: TCM3. Part II: Model Refinements and Sensitivity to Cloud Microphysics Parameterization. *Mon. Wea. Rev*. (in press)

Wu, L., and B. Wang, Assessing impacts of climate change on tropical cyclone tracks. To be submitted.